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(54) **SMART LINEAR ANGULAR POSITION SENSOR**
INTELLIGENTER LINEARWINKELPOSITIONSSENSOR
DETECTEUR INTELLIGENT DE POSITION ANGULAIRE LINEAIRE

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Description

[0001] The present invention relates to an electronic circuit for automatically compensating for part-to-part errors in a sensor and comprising the features of the pre-characterising clause of claim 1.

[0002] Sensors, as e.g., angular position sensors are known to be used for various purposes including throttle position sensors for determining the angular position of a butterfly valve in a throttle body. Examples of such sensors are disclosed in US 4,893,502 A and US 5,332,965 S. Such sensors are generally used to sense the angular position of the butterfly valve in the throttle body in order to control the amount of fuel applied to the combustion chamber of an internal combustion-engine.

[0003] Such throttle position sensors, as, e.g., the sensors disclosed in US 4,893,502 A and US 5,332,956 A, are typically subject to part-to-part variations which require each and every sensor to be calibrated either by the throttle body manufacturer as in the case of US 4,893,502 A or the sensor manufacturer as in the case of US 5,332,965 A. In the embodiment disclosed in US 4,893,502 A, a circular magnet is rigidly secured directly to the butterfly valve shaft. A magnet-resistive element (MRE) is disposed within a modified throttle body at a fixed air gap relative to the circular magnet. An amplifying circuit with variable gain is used to calibrate the sensor by way of potentiometers or variable resistors. As is known in the art, the output of such potentiometers may vary with temperature or time. Due to the relatively wide operating temperature range of such a sensor used in an internal combustion engine environment, such potentiometers will drift and affect the overall calibration of the device. The sensor disclosed in US 5,332,965 A is mechanically adjusted; and thus, the calibration is not subject to drift as in the case of US 4,893,502. However, such mechanical adjustments are time-consuming and cumbersome, which increases the overall labor cost to manufacture the product.

[0004] An electronic circuit such as specified in the pre-characterizing clause of claim 1 is known from each of the references EP 0 078 592 A2, GB 2 221 039 A and US 4,873,655 A. In each case the output signals obtained from a sensor are compared with previously stored calibration values for said sensor to obtain compensated output signals. However, whereas EP 0 078 592 anticipates the sensor to be practically linear, GB 2 221 039 A and US 4,873,655 A require relatively complicated circuitry including a microprocessor and a relatively large amount of memory space. Additionally, in the case of US 4,873,655 A, should an error occur in the stored calibration values, e.g. due to memory failure or an overvoltage condition, or an error result due to sensor output values drifting over time, complicated reprogramming is required for which the sensor assembly may even have to be dismounted and shipped to its manufacturer.

[0005] It is, therefore, the object of the present invention to provide a compensation circuit of the kind specified in the pre-characterizing clause of claim 1 which is less complicated and less expensive than known such circuits rendering a comparable result.

[0006] This is achieved by the present invention in the way as specified in claim 1. Starting therefrom, the dependent claims disclose preferred embodiments or further developments.

[0007] In that the stored calibration values are a sensitivity correction value and an offset compensation value each and these values are multiplied and, respectively, added directly to the sensor output signals thus to compensate the sensitivity as well as the offset of the sensor over a predetermined range of the sensor output the circuit of the invention requires significantly less components and memory space than comparable prior art circuits. Additionally, should an error ever develop in the stored calibration values, the sensor assembly can easily be recalibrated in place by merely programming a new offset calibration value and/or a new sensitivity calibration value, and this can be done at any local service center. The present invention can be implemented, if desired, without the use of a microprocessor in the operation mode and, accordingly, without the need for A-D and D-A converters.

[0008] In the following, a preferred embodiment of the circuit of the present invention will be described in detail, taking reference to the accompanying drawings, wherein:

Fig. 1 is a block diagram of an electronic compensation circuit in accordance with the present invention.

FIG. 2 is a graphical representation of the output voltage of an angular position sensor as a function of angular position, illustrating a sensor with and without the electronic circuitry illustrated in FIG. 1.

FIG. 3 is a schematic diagram of the electronic circuitry illustrated in FIG. 1.

FIG. 4 is a schematic diagram of a test interface in accordance with the present invention.

FIG. 5 is a block diagram of a test equipment for determining the compensation values in accordance with the present invention.

FIG. 6 is a block diagram of a personal 15 computer interface which forms a portion of the test equipment illustrated in FIG. 5.

FIG. 7 is a table of exemplary values of measured and ideal values at a plurality of predetermined calibration points.

FIG. 8 is a graphical representation of the measured values as a function of ideal values illustrated in FIG. 7.

FIGS. 9 and 10 are flow charts of the software for the test equipment illustrated in Fig. 5.

FIGS. 11 - 13 are flow charts of software for the electronic circuit in accordance with the present invention.

[0009] The electronic circuit 300 illustrated in Figs. 1 and 3 is to automatically compensate for any errors in the output signal due to the electronics, part-to-part variations of the magnet or temperature. The electronic circuit 300 includes an electronic memory 306, such as an electrically erasable read-only memory (EEPROM) for storing predetermined compensation values used to compensate the output signal of the sensor. The compensation values are determined by comparing the output signals of the sensor at predetermined calibration points, such as angles, with ideal values. The deviation between the actual values and the ideal values is used to determine the compensation values as discussed in more detail below. The compensation values are stored in the electronic memory 306 and used to automatically compensate the output signal of the sensor. As will be discussed in more detail below, the compensation of the output signals is done under software control which eliminates the need for mechanical adjustment of the sensor and provides automatic calibration.

[0010] An important aspect of the invention is that the electronic circuit 300 enables the compensation values to be determined by the sensor manufacturer and stored in the memory 306. Thus, once the sensors are shipped to the end user, the end user simply installs the sensor.

[0011] There are several error sources associated with such sensors. More particularly, such sensors may include a Hall effect device which typically includes on-chip operational amplifiers. Such operational amplifiers are frequently subject to offset errors which may vary from part-to-part. In addition, part to part variations in the magnetic flux distribution of the magnets used with such Hall effect devices also necessitates sensitivity adjustment of the Hall Effect device relative to the magnet. In addition, such sensors are also subject to error due to temperature variation.

[0012] The electronic circuit 300 in accordance with the present invention automatically compensates for such errors, thus obviating the need for mechanical adjustment. Although the electronic circuit 300 is discussed in terms of an angular position sensor, the principles of the present invention are applicable to virtually any sensor which provides an analog output signal.

[0013] In addition, although the electronic circuitry is discussed in terms of various discreet electronic components, as discussed below, the principles of the present invention are also applicable to other electronic components which generally perform the same basic functions. For example, all or a portion of the electronic circuitry described and illustrated below could be formulated into an application specific integrated circuit (ASIC). All such embodiments are considered to be within the broad scope of the invention.

[0014] Referring to Figure 1, the electronic circuit 300 includes an analog to digital converted (ADC) 302, for example, a twelve-bit serial ADC model number LTC 1298, as manufactured by Linear Technology, Inc., described in detail in LTC1286/LTC1298 MICROPOWER SAMPLING TWELVE BIT A/D CONVERTERS IN SO-8 PACKAGES, by Linear Technology, Inc., pages 6-140 to 6-162, hereby incorporated by reference. One input to the ADC 302 is the output of the sensor, for example a Hall effect device. The Hall effect device preferably is a linear device, for example, an Allegro model no. 3506, which provides a relatively linear output signal over the useful output range of the Hall effect device, as shown in Figure 2 and discussed below. A temperature sensor, for example a thermistor 330 (Fig.3) may also be applied to the ADC 302. The analog temperature and sensor signals are digitized by the ADC 302 under the control of a microcontroller 304, for example, a Motorola model number 68HC705J2, HCMOS Microcontroller, described in detail in HC05 MC68HC705J2 TECHNICAL DATA, by Motorola, Inc., copyright 1991, hereby incorporated by reference. The microcontroller 304 compares the digitized sensor output signal values from the ADC 302 with compensation values stored in the electronic memory 306, for example a MicroChip Technology, Inc., Model No. 93C46 CMOS EEPROM, described in detail in MICROCHIP 93CO6/46 256 BIT/1K 5B CMOS SERIAL EEPROM, BY MICROCHIP TECHNOLOGY, INC., COPYRIGHT 1994, hereby incorporated by reference. The deviations between the actual values from the ADC 302 and the stored compensation values from the electronic memory 304 are used by the microcontroller 304 to generate compensated output values that are applied to a digital to analog converter (DAC) 308. The DAC 308 may be a Maxim Model No. MAX539, 12 bit DAC described in detail in MAXIM 5V, LOW-POWER, VOLTAGE OUTPUT, SERIAL 12-BIT DAC'S MAX531 MAX538/MAX539 by Maxim Integrated Products, Copyright 1994, hereby incorporated by reference. The DAC 308, in turn, provides a compensated analog output voltage signal V_{OUT}.

[0015] The electronic circuitry 300 includes a test interface 310 which enables the compensation values to be determined, for example by the sensor manufacturer, and programmed into the electronic memory 306. The test interface 310 is connected to the balance of the electronic circuitry 300 by a pair of cables 312 and 314. The cable 312 is connected between the test interface 310 and the microcontroller 304 while the cable 314 is connected between the test interface 310 and the electronic memory 306. These cables 312 and 314 allow for serial communication between the electronic circuitry 300 and the test interface 310 to enable the compensation values to be determined. More particularly, as will be discussed in more detail below, in a CALIBRATE mode, the angular position sensor is tested at a predetermined number of calibration points (e.g., angular positions). The output signals from the sensor at the predetermined calibration points are then compared with the ideal values for each point to determine the deviation of the actual values from the compensation values. These deviations are used to determine the compensation values for each distinct sensor. The compensation values are, in turn, programmed into the electronic memory 306. Once the compensation values are programmed into the electronic memory 306, the test interface 310 may be disconnected

from the electronic circuitry 300.

[0016] FIG. 2 is a graphical representation of the automatic compensation of the electronic circuitry 300. In particular, the output signal of the sensor as a fraction of the power supply voltage VS along the vertical axis is plotted as a function of an exemplary angular operating range, for example 90 degrees. The curve 316 represents the output of the sensor without compensation over the exemplary operating range of the sensor while the curve 318 represents the output of a sensor assembly which incorporates the electronic circuit 300 in accordance with the present invention. The curve 318 corresponds with the ideal values.

[0017] Although the output curve for a typical sensor is not perfectly linear as illustrated in FIG. 2, the curve can be approximated on a piecemeal linear basis to generate the ideal curve 318 in response to sensor values along the curve 316. As such, the electronic circuit 300 is adapted to provide automatic compensation for the sensor output signal. The determination of the compensation values is discussed in detail below.

[0018] A schematic diagram for the electronic circuitry 300 shown in FIG. 1 is illustrated in FIG. 3, while a schematic diagram for the test interface 310 is illustrated in FIG. 4. Referring first to FIG. 3, an oscillator signal for the microcontroller 304 is provided by an oscillator circuit 320, for example an AVX KYOCERA, KBR-4.00-MKS TR Ceramic Resonator, as described on a data sheet entitled, KBR-MKS SERIES CERAMIC RESONATORS, P14 BY AVX KYOCERA, hereby incorporated by reference. The oscillator circuit 320 is connected to the oscillator pins OSC1 and OSC2 of the microcontroller 304, along with a parallel connected resistor 322 to form a parallel resonance circuit, for providing, for example, a 4 megahertz (mHz) oscillator signal to the microcontroller 304.

[0019] The microcontroller 304 includes an 8-bit port PA[7:0] and a 6-bit port PB[5:0]; all of the bits being programmable as either input or output ports by way of data direction registers on board the microcontroller 304. A CALIBRATE mode signal is applied to a port bit PB[3]; programmed as an input port bit. The CALIBRATE mode signal is available at a test equipment 402 (FIG. 5) by way of the test interface 310 (FIG. 4). As will be discussed in more detail below, the CALIBRATE mode signal is enabled when the test equipment 402 is being used to determine the compensation values to be written to the memory 306. In particular, the port bit PB[3] is normally pulled high by a pull-up resistor 324, connected between the port bit PB[3] and the sensor 5 volt power supply VCC. Normally, the port bit PB[3] will be high. During the CALIBRATE mode, the CALIBRATE signal pulls the port bit PB[3] low to let the microcontroller 304 know the system is in the CALIBRATE mode.

[0020] A SENSOR IN signal, such as from an analog Hall effect device, is applied to one channel CH0 of the ADC 304, which includes a two-channel multiplexed input at pins CH0 and CH1. The output of the thermistor 330 is applied to the other channel, CH1, by way of an operational amplifier 326 and a serially connected resistor 328. The output of the operational amplifier 326 is applied to the second input CH1 of the ADC 304.

[0021] The ADC 302 is a two-channel device and communicates with the microcontroller 304 by way of a synchronous half-duplex 4-wire serial interface. In particular, the serial interface includes a clock signal CLK, a chip select signal CS, a digital data input signal DIN and a digital data output signal DOUT, applied to port bits PA[3], PA[1], PA[2] and PA[0] respectively. The port bits PA[3], PA[2] and PA[1] are configured as outputs while the port bit PA[0] is configured as an input.

[0022] Data transfer between the microcontroller 304 and the ADC 302 is initiated by a falling edge of the chip select signal CS. The clock signal CLK synchronizes the data transfer in both directions. After the chip select signal CS goes low, the ADC 302 awaits a start bit on the data input pin DIN. The first logical one shifted into the data input DIN pin after the chip select signal CS goes low represents the start bit. The next three bits shifted in after the start bit are used to configure the ADC to the select one of the input signals at the CH0 and CH1 inputs for conversion and to specify whether the most significant bit (MSB) or the least significant bit (LSB) is shifted out first on the data out pin DOUT. After the start bit and three configuration bits are shifted into the data input pin DIN, the conversion process begins. Any additional bits shifted into the data input pin DIN are ignored until the next chip select CS cycle.

[0023] Data transfer between the microcontroller 304 and the test interface 310 are handled in a similar manner. In particular, four signals, a data out signal COMPOUT, a data in signal COMPIN, a clock signal EXCLK, and a chip select signal EPCS are used to control serial communication between the test interface 310 and the microcontroller 304. Each of the signals COMPOUT, EXCLK, EPCS and COMPIN are tied high by way of pull-up resistors 328, 330, 332 and 334, respectively.

[0024] The COMPOUT and COMPIN signals are used for handshaking and data communication between the microcontroller 304 and the test interface 310. The COMPIN signal is available at port bit PB[5] of the microcontroller 304 configured as an output. The COMPIN signal is also used to read serial data from the data output pin DO when the system is not in the CALIBRATE mode. The COMPOUT signal from the test interface 310 is applied to the port bit PB[4] of the microcontroller 304 and to the clock input of the memory 306. The COMPOUT signal is used for writing to the memory 306 as well as handshaking with the microcontroller 304. The chip select signal EPCS from the test interface 310 is used to enable the conversion values from the ADC 302 to be transferred to the test equipment 402 (Fig.5) for determination of the compensation values when the chip select EPCS is deselected and to enable the compensation values to be written to the memory 306 when the chip select signal EPCS is selected. The clock signal

EXCLK is applied to the data input pin DI of the memory 306 and to the port bit PA[7] of the microcontroller 304 to control the bit by bit transfer of the 12 bit output of the ADC 302 when the test equipment 402 is reading digitized sensor and thermistor values from the microcontroller 304 and controls the bit-by-bit writes to the memory 306. A start bit is determined after the data input pin DI and chip select pins CS on the memory 306 are high for the first time relative to the clock input CLK.

[0025] As discussed above, the values from the sensor are corrected by the compensation values stored in the memory 306. The compensated values are converted to analog form by the DAC 308 under the control of the microcontroller 304. In particular, the DAC 308 includes a chip select pin CS, a data input pin DI, a data output pin DOUT and a clock pin CLK, that are controlled by the microcontroller 304. These pins are connected to port pins PA[4], PA [6] PA[5] and PA[0], respectively, on the microcontroller 304 and are all configured as outputs. The data output pin DOUT on the DAC 308 enables the digital data from the DAC 308 to be read back by the microcontroller 304. The analog output of the DAC 308 is available at an output pin V_{OUT} and is coupled to an external circuit (not shown) by way of a resistor 336.

[0026] A reference voltage, for example, developed by an operational amplifier 338 and a pair of serially connected resistors 340 and 342, configured as a voltage divider, are applied to a reference input REFIN of the DAC 308. The reference voltage is used to set the full scale output of the DAC 308.

[0027] In order to assure proper operation of the microcontroller 304, interrupt request pin IRQ is tied high, and, in particular, connected directly to the 5 volt supply VCC, since the system does not need to monitor any interrupts. The microcontroller 304 is reset by way of its reset pin RESET. The RESET pin is normally pulled high by a pull-up resistor 344, connected between the power supply voltage VCC and the RESET pin. In order to prevent spurious operation of the signal applied to the RESET pin, a capacitor 346 is coupled between the RESET pin and ground. The microcontroller 304 is reset by way of a pushbutton 348, connected between the RESET pin and ground. Normally, the RESET pin is high. When the RESET push button 348 is depressed, the RESET pin is brought low to indicate a forced RESET to the microcontroller 304. In order to stabilize the power supply voltage to the microcontroller 304, a plurality of capacitors 350, 352, 354, 356, 358 and 360 are connected between the 5 volt sensor supply VCC and the sensor ground.

[0028] The schematic diagram for the test interface 310 is shown in Fig. 4. In order to provide electrical isolation between the test interface 310 and the electronic circuit 300, a plurality of optical isolators 362, 364, 366, 368, 370 and 372 are used to isolate connections between the test interface 310 and the electronic circuitry 300. The signals with the suffix _.TSET indicate connection to the test equipment 402 (FIG. 5) while the signals with the suffix _.PCB indicate connection to the electronic circuit 300 (FIG. 3).

[0029] Each of the optical isolators 362, 364, 366, 368, 370 and 372 includes a light-emitting diode (LED) and a photo-transistor. The anodes of each of the LEDs are connected to the power supply voltage VCC by way of current-limiting resistors 374, 376, 378, 380, 382 and 384. The cathode of each of the LEDs is connected to the appropriate signals as will be discussed below. In operation, when the signals connected to the cathodes of the LEDs are brought low, the LEDs will emit light which will be sensed by the photo-transistors. The photo-transistors are connected with their emitters grounded. The collectors are connected to the various signals discussed above. As will be discussed in more detail below, the collectors are normally pulled high and go low when light is sensed from the LEDs. More particularly, a CALIBRATE_TSET signal from the test interface 310 is applied to the anode of the optical isolator of the LED forming the optical isolator 362. The collector of the photo-transistor is the CALIBRATE signal, which, as discussed above, is applied to the port PB[3] of the microcontroller 304.

[0030] As mentioned above, the COMPIN, COMPOUT, EXCLK and EPCS signals are used for forming a serial communication interface between the microcontroller 304 and the test equipment 402 illustrated in FIGS. 5 and 6. The signals COMPOUT_TSET, EXCLK_TSET, and EPCS_TSET, available from the test equipment 402 (FIG. 5), are applied to the cathodes of the LEDs forming the optical isolators 364, 366 and 368, respectively. The collector outputs of the optical isolators 364, 366, 368 are tied high by way of pull-up resistors 382, 384, and 386, respectively. As mentioned above, the emitter terminals of each of the photo-transistors associated with the optical isolators 364, 366 and 368, respectively, are grounded. Thus, during normal operation the collectors of the optical transistors associated with the optical isolators 364, 366 and 368 will be high. When the signals COMPOUT_TSET, EXCLK_TSET, EPCS_TSET go low, the collector outputs of the photo-transistors associated with the optical isolators 364, 366 and 368 will go low. The collectors of the photo-transistors associated with the optical isolators 364, 366 and 368 are applied to a pair of serially connected NOT gates 388, 390, 392, 394, 396 and 398; for example type 74HC14, which act as buffers to buffer the output of the optical transistors associated with the optical isolators 364, 366 and 368.

[0031] In order to provide isolation of the test interface 310 from the balance of the electronic circuit 300 when the system is not in the CALIBRATE mode, the signals COMPOUT_TSET, EXCLK_TSET, EPCS_TSET and COMPIN_PCB are applied to a quad-tristate device, for example a type 74C 244. In particular, the COMPOUT signal, available at the output of the NOT gate 390, is applied to an input 1A2, while the COMPIN signal available at port bit PB[5] of the microcontroller 304 (Fig. 3), is applied to the 1A4 input of the tristate device 400. Similarly the EXCLK and EPCS signals, available at the outputs of the NOT gates 394 and 398, respectively, are applied to the 1A3 and 2A1 inputs of

the tristate device 400.

[0032] The tristate device 400 provides yet another isolation interface between the test interface 310 and the electronic circuit 300. In particular, the COMPOUT_PCB, EXCLK_PCB, and EPCS_PCB signals, available at the 1Y2, 1Y3 and 2Y1 outputs of the tristate device 400 are connected to the microcontroller 304 (Fig. 3), as discussed above. The EPCS_TSET and COMPIN_TSET signals, available at the 2Y1 and 1Y4 outputs of the tristate device 400, are isolated by the optical isolators 370 and 372 in a similar manner as discussed above and applied to the test equipment 402.

[0033] The tristate device 400 is under control of buffer enable signals BUFEN1_TSET and BUFEN2_TSET, available at the test equipment 402. As will be discussed in detail below, during the CALIBRATE mode, the tristate device 400 will be enabled thus connecting the serial communication control signals between the test equipment 402 and the electronic circuit 300 by way of the optical isolation circuits discussed above. During conditions other than the CALIBRATE mode the tristate device 400 provides electrical isolation of the electronic circuit 300 from the test interface 310.

[0034] The test equipment 402 is illustrated in Fig. 5. It includes a power supply 404 which provides a 5 volt DC voltage supply for the sensor. The power supply 404 may be a Hewlett Packard Model No. E3620 A. The power supply voltage is monitored by a Continuing Conformance Tester 406, for example, a S/N 95015 by Altech Control Systems. The Continuing Conformance Tester 406 monitors the voltage from the power supply 404 to ensure that it is within proper limits. As will be discussed below, the Continuing Conformance Tester 406 includes a personal computer 418 and various peripherals as illustrated in Fig. 6. In the CALIBRATE mode the Continuing Conformance Tester 406 positions the sensor 43 (Fig. 5) to predetermined calibration points, here by monitoring an Absolute Position Encoder 408, for example, a model No. M25G-F1-L8192-G-XD2-CR-E-C25-X-5 by BEI Motion Systems Company, Positions Controls Division. By monitoring the Absolute Position Encoder 408, the Continuing Conformance Tester 406 is able to supply an error voltage to a motor controller 410, for example, a model number SC401-01-T1 by Pacific Scientific Motor & Control Division, proportional to the distance away from the required angle. The motor controller 410 drives a servo motor 412, for example, a model R21KENT-TS-NS-NV-00 by Pacific Scientific Motor & Control Division. The servo motor 412 in turn drives a servo actuator 414, for example, a model number RH-100-CC-SP by Harmonic Drive Systems, Inc. which, in turn, positions the sensor 43 to a predetermined calibration point. The sensor 43 may be disposed in a chamber in which the temperature is set to a predetermined value for all of the calibration points. The chamber 416 may be a Versa 10 type oven, as manufactured by Tenney Engineering Inc.

[0035] As mentioned above, the motor controller 410 controls the operation of the servomotor 412 and in turn the servo actuator 414 to drive the sensor 43 to predetermined calibration angles. A positive voltage from the Continuing Conformance Tester 406 forces the servomotor 412 to move clockwise while a negative voltage moves the servomotor 412 counter-clockwise. The sensor voltage is read at each calibration point. After all of the calibration readings are taken the deviation between the values measured at the calibration points (i.e., the actual values) and the ideal values is determined for each position of the sensor. Compensation values are then written into the memory 306.

[0036] As mentioned above, the Continuing Conformance Tester 406 is provided with a personal computer 418 (FIG. 6) which should include at least an 80486 DX or equivalent microprocessor. The Continuing Conformance Tester 418, in addition to the personal computer 418, may include a digital volt meter 420 for measuring the voltage of the sensor and the power supply 404 as well as a user-interface which includes a keyboard 422 and a monitor 424. The Continuing Performance Tester 406 may also include a tape back-up system 426 and a printer 428 as well as a status board 430 for providing an indication of the status of the system.

[0037] As mentioned above, the test equipment 402, illustrated in Fig. 5, is interfaced with the electronic circuit 300 by way of the test interface 310. As will be discussed in more detail below, the test equipment 402 including the personal computer 418 forming a portion of the Continuing Conformance Tester 406 is used to communicate with the microcontroller 304 in order to determine the compensation values for the sensor over a predetermined operating range. The software control for the personal computer 418 is illustrated in FIGS. 9 and 10.

[0038] A key aspect of the invention is the method for determining the calibration values. As mentioned above the test equipment 402 positions the sensor 43 at various predetermined calibration points and determines the sensor output value at each of the points. These calibration points taken at a predetermined temperature, for example 25°C, are, in turn, compared with ideal values. The deviation between the actual values and the deviation values is used to develop a compensation value that is written to the memory 306. The method for determining the compensation value is best understood with references to Figs. 7 and 8. In particular, the output voltage of the sensor is measured at a predetermined number of calibration angles. The calibration angles as well as the other values illustrated in Figs. 7 and 8 are exemplary. It is to be understood that virtually any number of calibration angles and values are within the scope of the present invention. Referring first to Fig. 7, the sensor output voltage is measured at 8 calibration angles θ_0-θ_7, which, for example, have been selected between 14.4° and 92.4° for discussion purposes. The particular calibration angles will vary as a function of the application of the sensor. The sensor output voltage at each of the calibration angles θ_0-θ_7 is measured and plotted along an X axis as shown in Fig. 8. The actual or measured values are then compared with the ideal values for each of the calibration angles θ_0-θ_7 which are plotted along a Y axis as shown in Fig. 8.

[0039] As discussed above, throughout the useful range of the sensor the output voltage of the sensor is assumed to be linear,as illustrated in Fig. 2. Thus, between each of the calibration angles θ_0-θ_7 the response is assumed to be linear. As such the compensation values are determined by determining the *slope m* and *y-intercept b* of the line segments 432 (Fig. 25) for each of the calibration angles θ_0-θ_7. The *slope m* and *y-intercept* b between each of the calibration angles θ_0-θ_7 is determined and written to the memory 306 in order to provide automatic compensation of the measured values by the analog input. In particular, the system measures actual values X of the sensor output. Since the ideal values are assumed to be linearly related to the actual values, the actual value is multiplied by the *slope m* and added with the *y-intercept b* to produce an ideal value. Since the *slope m* and *y-intercept b* compensation values vary between each calibration angle, the microcontroller 304 first determines the particular correction *slope m* and *y-intercept b* to be used. This is done by comparing the measured output voltages with the ideal voltages to determine the particular correction slope and y-intercept to be used. For example, referring to Fig. 7, assume that a value of 1.4 was measured by the sensor. The system would compare this measured value of 1.4 with the ideal values and ascertain that the calibration angle was between 20.4 and 34.8. In such a situation, since the compensation values are assumed to be linear between successive predetermined calibration angles, the slope compensation and y-intercept compensation values associated with the angle 20.4 would be used. Thus in such an example, the voltage of 1.4 volts would be multiplied (using the exemplary data illustrated in Fig. 7) by the value 1.448. The y-intercept b of -0.862 would be subtracted from that value to render an ideal voltage in that range.

[0040] A flow chart for the test equipment 402, in particular the personal computer 418 for determining the compensation values, is illustrated in Figs. 9 and 10. A flow chart for providing a compensated output value for the sensor by the microcontroller 304 is illustrated in Figs. 11 - 13. Referring first to Figs. 9 and 10, the system starts by setting the CALIBRATE mode and in particular, generating an active low CALIBRATE signal that is applied to the test interface 310 and in particular to the optical isolator 362 in step 440. Once the CALIBRATE mode is enabled, the test equipment 402 initiates a handshake with the microcontroller 304. In particular, in step 442, the COMPOUT signal is set low and the tristate device 400 is enabled in step 442 by setting the BUFEN1-TSET and BUFEN2_TSET signals. The COMPOUT signal is applied to the optical isolator 364 and indicates to the microcontroller 304 that the test equipment 402 is ready to initiate determination of the compensation values as discussed above. The enable signals for the tristate device 400 BUFEN1_TSET, and BUFEN2_TSET are applied to the 1G, 2G respectively pins of the tristate device 400. These signals are active low in order to enable the tristate device 400. After the COMPOUT signal is set low and the tristate device 400 is enabled, the system waits for a predetermined time period, for example, 10 milliseconds, in step 444 to determine if the microcontroller 304 is ready. After the 10 millisecond time period the system reads the COMPIN_TSET signal, available at the output of the optical isolator 372 as part of the handshake between the microcontroller 304 and the personal computer 418. If the COMPIN_TSET signal has not been set low, the system returns to step 446 and awaits the handshake from the microcontroller 304. Once the COMPIN_PCB signal is pulled low by the micro-controller 304 the COMPIN_TSET signal is read by the personal computer 418 at the output of the optical isolator 372. If the COMPIN_TSET signal is low, the personal computer 418 sets the COMPOUT_TSET signal high in step 448 and waits for a predetermined time period, for example 1 millisecond. Subsequently, the personal computer 418 pulls the COMPOUT signal low in step 450 and waits 1 millisecond. Afterwards, the personal computer 418 checks the status of the COMPIN signal from the microcontroller 304. If the COMPIN signal is low the system recycles back to step 450. Once the COMPIN signal is set high by the microcontroller 304, as ascertained in step 452, the personal computer 418 sets the COMPOUT signal high in step 454 to let the microcontroller 304 know that the handshake is complete. After the handshake is complete, the system proceeds to step 456 and reads the digitized sensor output voltage at the port bit PB[5] of the microcontroller 304 on the COMPIN line. In particular, the sensor output voltage is digitized by the ADC 302 under the control of the microcontroller 304. The digitized 12 bit value is made available at the port bit PB[5], one bit at a time, and communicated serially to the personal computer 418 under the control of the clock signal EXCLK. In addition to measuring the sensor voltage in step 456, the system also measures the thermistor voltage. In particular, while the digitized sensor voltage is being read, the microcontroller 304 configures the ADC 302 to digitize the analog signal on channel 0 (CH0). When the thermistor voltage is being read, the microcontroller 304 configures the ADC 302 to read the thermistor voltage on channel 1 CH1. After the digitized sensor voltage and thermistor voltage are read in step 456, the system starts cycling the sensor through the predetermined calibration angles, for example θ_0-θ_7,.(FIG. 7). In particular, in steps 458 et seq., the system commands the test equipment 402 to position the sensor at each one of the calibration angles θ_0-θ_7. Initially, for the first calibration angle θ_0, the test equipment 402 is configured to place the sensor at angle θ_0 in step 460 and to set the COMPOUT signal low. Subsequently, in step 462, the system ascertains whether the microcontroller 304 has acknowledged that the sensor is being calibrated at the initial calibration angle θ_0 by determining whether the microcontroller 304 has pulled the COMPIN signal high. If not, the system loops back to step 462 and awaits for the COMPIN signal to be pulled high by the microcontroller 304. Once the COMPIN signal goes high the personal computer 418 sets the COMPOUT signal high in step 464. After the COMPOUT signal has been set high in step 464, the system awaits an acknowledgment by the microcontroller 304 by determining whether the COMPIN signal has been set low in step 466. If not, the system loops back to step 466

and awaits acknowledgment by the microcontroller 304. Once the COMPIN signal is set low, the personal computer 418 sets the COMPOUT signal low in step 468. After the COMPOUT signal is set low, the system awaits acknowledgment by the microcontroller 304 by determining whether the COMPIN line has been set high in step 470. If not, the system awaits the acknowledgment by the microcontroller 304 and returns to step 468. Once the microcontroller 304 acknowledges the personal computer 418 by setting its COMPIN signal high, the personal computer 418 sets its COMPOUT signal high in step 472. Subsequently the actual sensor values are read in steps 474 and 476. For the first time through the loop I is set to zero and thereafter incremented in step 478. In step 480 the system determines whether I is less than the total number of readings required. As indicated above, eight exemplary readings may be taken at calibration angles θ_0-θ_7. If less than all of the readings have been taken,the system proceeds to Fig. 10 and calculates the slope and intercept of the actual measurements versus the ideal values in steps 482, 484, 486 and 488, as discussed above. The steps 460 through 488 are cycled until the slopes m and y-intercepts b have been determined for all the calibration angles θ_0-θ_7. Once all of the calculations have been made for a particular sensor, the system proceeds to step 490 in order to initiate writing of the compensation values to the memory (EEPROM) 306. In particular, in step 490, the COMPOUT signal is set high. This signal is tied to the data input DIN of the memory 306 and is used to initiate a write to the memory 306 in a manner as discussed above. In addition, the system selects the memory 306 by setting the signal EPCS high, which, in turn, is tied to the chip select pin CS of the memory 306. In addition, the CALIBRATE mode is disabled by pulling the CALIBRATE signal high. Subsequently, in step 492, the system checks to determine if the chip select pin CS of the memory 306 has been set, since this pin is also under the control of the microcontroller 304 and in particular the port bit PB[0]. If the chip-select signal EPCS for the memory 306 is not high, the system waits, in step 490, until the chip select signal EPCS is high. Once the chip select signal EPCS goes high, the CALIBRATE mode is enabled by pulling the CALIBRATE signal low in step 494. In addition, as discussed above, the memory 306 is prepared for writing. In steps 496, 498, 500 and 502 the system writes all of the calibration points, and, in particular, the slopes m and y-intercepts b for each of the calibration points θ_0-θ_7 to the memory 306. As indicated above, communication to the memory 306 is serial with bits being clocked in one bit at a time under the control of the clock signal EXCLK. After all the compensation values have been written to the memory 306, the system disables the WRITE mode for the memory 306 in step 504. After the WRITE mode for the memory 306 has been disabled, the contents of the memory 306 are verified in steps 506 and 508 for errors. If no errors are found in the contents of the memory 306 the system proceeds to step 510 where the CALIBRATE mode is disabled as well as the buffer enable signals BUFEN1_TSET and BUFEN2_TSET to disable the tristate device 400, which, in essence, disconnects the test equipment 402 from the interface 310. If errors are detected in step 508, the user is notified of the errors by way of the monitor 424 (FIG. 6) in step 512 with the system subsequently going to step 510. After the CALIBRATE mode and buffer enable signals are disabled, the tristate device 400 is disabled. The system proceeds to step 514 and prints a message on the monitor 424 that the programming of the memory 306 is complete and was successful.

[0041] The flow charts for the microcontroller 304 are illustrated in FIGS. 11 - 13, Initially the system determines, in step 516, whether the CALIBRATE mode of operation has been selected. If not, the system proceeds to step 518 and assumes a NORMAL mode is selected and executes the code illustrated in Fig. 13 for NORMAL mode. If the system is in the CALIBRATE mode, as determined by reading the CALIBRATE signal applied to port bit PB[3], the microcontroller 304 proceeds to step 520 and determines whether the compensation values need to be programmed into the memory 306. If not, the system assumes a CALIBRATE mode and proceeds to step 522 and the software illustrated in Fig. 12. Otherwise, the correction factors are written to the memory 306 and verified in step 524.

[0042] The CALIBRATE mode is initiated in step 526. Initially, in step 528, the serial interface is initialized. After the serial interface is initialized, the microcontroller 304 determines whether a reading is being requested in step 530. If not, the system waits at step 530 for such request. If a calibration reading has been requested, the sensor voltage or thermistor voltage is read and sent to the test equipment 402 over the serial interface in step 532. The system next determines, in step 534, whether all readings have been taken. If not, the system returns to step 530. If so, the system proceeds to step 536 and determines the correction values to be programmed to the memory 306.

[0043] The NORMAL mode is illustrated in Fig. 13 and is initiated in step 538. Initially, in step 540 the system ascertains whether the system is in the NORMAL mode by monitoring the logic level of the CALIBRATE signal. If the CALIBRATE signal is high, the NORMAL mode is indicated and the sensor voltage is determined. After the sensor voltage is read, the proper correction factor from the memory 306 is determined in step 542. Subsequently, in step 544, the measured value is multiplied by the *slope* m correction factor. Next, in step 546, the *y-intercept b* is added to the result obtained from step 544. Lastly, in step 548, the adjusted output voltage is applied to the DAC 308 which in turn provides a corrected sensor output voltage V_{OUT}.

[0044] The system also provides for thermal compensation. As mentioned above, the compensation values are determined at a particular temperature, for example 25°C. The readings are provided by the thermistor 330, for example, a Yageo 1% metal film fixed resistor. The temperature compensation is accomplished by assuming, for example, a -3% deviation at 150°C in the output signal due to temperature when the sensor is hot and a +1% deviation at -40°C in the output signal when the sensor is cold. Whether the sensor is hot or cold is determined by comparing the thermistor

voltage V_{THM} with the thermistor voltage V_{AMB} at the temperature at which the compensation values were taken. If the compensation values were determined at a 25°C ambient, then V_{AMB} is the thermistor voltage at 25°C. Thus, if the thermistor voltage V_{THM} is > V_{AMB}, the system is assumed to be hot and a 3% tolerance is assumed. If the thermistor voltage V_{THM} is < V_{AMB}, the system is assumed to be cold and a 1% tolerance is assumed. For a 5 volt system, it is assumed that at the null point voltage $V_{CROSSOVER}$ of the sensor (i.e. output voltage at which the output signal indicates 0 gauss), there is no shift in the output voltage due to temperature deviation. The deviation is thus determined by the following equation:

$$DEV = +/- [\frac{V_{AMB}-V_{THM}}{V_{THM}} * TOLERANCE*(V_{MEASURED} - V_{CROSSOVER})]$$

If the system is hot, the deviation is added to the measured voltage. If the system is cold, the deviation is subtracted from the measured voltage.

[0045] The temperature tolerances as well as the thermistor voltage readings are linearized to provide a more accurate output. Also a resistor (not shown) of the same value as the thermistor may be connected in parallel with the thermistor. For a 3% total tolerance, the tolerance can be linearized by assuming the tolerance varies linearly over the 3% total tolerance range and the temperature range. Assuming the tolerance is in the general form of y = mx + b, for a 3% tolerance over a 125°C temperature range (i.e. 150°C-25°C), the *slope m* will be 0.00024 and the *y-intercept b* will be -0.006.

[0046] In order to linearize the thermistor voltage V_{THM} values, the voltages are read at the temperature extremes, 25°C and 150°C. Assuming that V_{THM} is in the general form $y = mx + b$, the *slope* and *y-intercept b* can be determined. For example at 25°C, V_{THM} is 2.3832212 volts and at 150°C, V_{THM} = 0.1591433, the *slope m* will be -56.2031 and the *y-intercept b* will be 158.9444. Thus, the temperature will be equal to $-56.2031\ V_{THM} + 158.944$. For a 3% tolerance, the tolerance is equal to $0.00024 * TEMP - .006$. Substituting the value for the temperature yields a tolerance of $-0.03488744\ V_{THM} + 0.03214656$. The tolerance is then substituted into the equation above for the deviation DEV in order to determine the amount of temperature compensation.

[0047] In a similar manner, the tolerance thermistor voltage V_{THM} is linearized for a 1% tolerance. These values are then used to determine the deviation as discussed above.

[0048] While the invention has been described with reference to details of the embodiments shown in the drawings, these details are not intended to limit the scope of the invention as described in the appended claims.

Claims

1. An electronic circuit (300) for automatically compensating for part-to-part errors in a sensor (43) for generating compensated output signals in response to sensor output signals, said circuit comprising compensating means (304, 306, 308 etc.) for automatically compensating part-to-part errors in said sensor output signals, said compensating means including means for measuring the output value of said sensor and storing means (306) for storing predetermined calibration values for said sensor at predetermined calibration points over a predetermined output range of said sensor, and means for generating said compensated output signals on the basis of present sensor output signals and said stored calibration values,
   characterized in that said storing means (306) store ideal values for said sensor (43) over a predetermined output range of said sensor along with said predetermined calibration values, wherein said predetermined calibration values used for compensation are selected as a function of said ideal values and said measured values, said calibration values including a slope value and an offset value, and said compensating means (304, 306, 308 etc.) are configured to multiply said measured value by said slope value to define a product and to add said offset value to said product for compensating the sensitivity as well as the offset of said sensor output signals.

2. The electronic circuit (300) of claim 1, wherein said compensating means (304, 306, 308 etc.) include means (330) for automatically compensating for errors in said sensed output signals resulting from temperature deviations.

3. The electronic circuit (300) of claim 1 or 2, wherein said sensor (43) is an analog sensor.

4. The electronic circuit (300) of claim 3, wherein said sensor (43) is a linear sensor.

5. The electronic circuit (300) of claim 3 or 4, wherein said sensor (43) is a Hall-effect sensor.

6. The electronic circuit (300) of any one of the preceding claims, wherein said compensating means (304, 306, 308 etc.) is on-chip relative to said sensor (43).

7. The electronic circuit (300) of any one of the preceding claims, wherein said compensated output signals are analogue signals.

8. The electronic circuit (300) of any one of the claims 1 to 6, wherein said compensated output signals are digital signals.

9. The electronic circuit (300) of any one of the preceding claims, wherein said storing means (306) comprise a non-volatile memory for storing said calibration values.

10. The electronic circuit (300) of claim 9, wherein said non-volatile memory is an electrically erasable programmable read only memory (EEPROM).

11. The electronic circuit (300) of any one of the preceding claims, wherein said sensor (43) is an angular position sensor.

Patentansprüche

1. Elektronische Schaltung (300) zum automatischen Kompensieren von von Stück zu Stück auftretenden Fehlern bei einem Sensor (43) zum Erzeugen kompensierter Ausgangssignale auf Sensorausgangssignale. hin, wobei die Schaltung Kompensationsmittel (304, 306, 308 etc.) zum automatischen Kompensieren von von Teil zu Teil auftretenden Fehlern in dem Sensorausgangssignal aufweist, die wiederum Mittel zum Messen des Ausgangswerts aus dem Sensor und Speichermittel (306) zum Speichern vorbestimmter Eichwerte für den Sensor an vorbestimmten Eichpunkten über einen vorbestimmten Ausgangsbereich des Sensors sowie Mittel zum Erzeugen der kompensierten Sensorausgangssignale auf der Basis von gegenwärtigen Sensorausgangssignalen und den gespeicherten Eichwerten aufweist,
dadurch gekennzeichnet, daß die Speichermittel (306) Idealwerte für den Sensor (43) über einen vorbestimmten Ausgangsbereich des Sensors zusammen mit den vorbestimmten Eichwerten speichern, wobei die für die Kompensation verwendeten vorbestimmten Eichwerte in Abhängigkeit von den Idealwerten und den gemessenen Werten gewählt werden sowie einen Steigungswert und einen Versetzungswert aufweisen und die Kompensationsmittel (304, 306, 308 etc.) so beschaffen sind, daß sie in der Lage sind, den gemessenen Wert mit dem Steigungswert zu multiplizieren, um ein Produkt zu definieren, und den Versetzungswert zu dem Produkt hinzuzuaddieren zum Kompensieren der Empfindlichkeit wie auch der Versetzung der Sensorausgangssignale.

2. Elektronische Schaltung (300) nach Anspruch 1, worin die Kompensationsmittel (304, 306, 308 etc.) Mittel (330) zum automatischen Kompensieren von Fehlern in den erfaßten Ausgangssignalen aus Temperaturabweichungen enthalten.

3. Elektronische Schaltung (300) nach Anspruch 1 oder 2, worin der Sensor (43) ein Analog-Sensor ist.

4. Elektronische Schaltung (300) nach Anspruch 3, worin der Sensor (43) ein linearer Sensor ist.

5. Elektronische Schaltung (300) nach Anspruch 3 oder 4, worin der Sensor (43) ein Hall-Effekt-Sensor ist.

6. Elektronische Schaltung (300) nach einem der vorhergehenden Ansprüche, worin die Kompensationsmittel (304, 306, 308 etc.) in bezug auf den Sensor (43) on-chip angeordnet sind.

7. Elektronische Schaltung (300) nach einem der vorhergehenden Ansprüche, worin die kompensierten Ausgangssignale AnalogSignale sind.

8. Elektronische Schaltung (300) nach einem der Ansprüche 1 bis 6, worin die kompensierten Ausgangssignale Digital-Signale sind.

9. Elektronische Schaltung (300) nach einem der vorhergehenden Ansprüche, worin die Speichermittel (306) einen nichtflüchtigen Speicher zum Speichern der Eichwerte enthalten.

10. Elektronische Schaltung (300) nach Anspruch 9, worin der nichtflüchtige Speicher ein elektrisch löschbarer programmierbarer Festwertspeicher (EEPROM) ist.

11. Elektronische Schaltung (300) nach einem der vorhergehenden Ansprüche, worin der Sensor (43) ein Winkelpositionssensor ist.

Revendications

1. Circuit électronique (300) pour compenser automatiquement des erreurs point à point dans un capteur (43) pour générer des signaux de sortie compensés en réponse aux signaux de sortie du capteur, ledit circuit comportant des moyens de compensation (304, 306, 308, etc.) pour compenser automatiquement des erreurs point à point dans lesdits signaux de sortie du capteur, lesdits moyens de compensation incluant des moyens pour mesurer la valeur de sortie dudit capteur et des moyens de stockage (306) pour stocker des valeurs d'étalonnage prédéterminées pour ledit capteur à des points d'étalonnage prédéterminés sur une plage de sortie prédéterminée dudit capteur, et des moyens pour générer lesdits signaux de sortie compensés sur la base des signaux de sortie du capteur présents et lesdites valeurs d'étalonnage calibrage stockées, **caractérisé en ce que** lesdits moyens de stockage (306) stockent des valeurs prescrites pour ledit capteur (43) sur une plage de sortie prédéterminée dudit capteur avec lesdites valeurs d'étalonnage prédéterminées, où lesdites valeurs d'étalonnage prédéterminées utilisées pour la compensation sont sélectionnées comme une fonction desdites valeurs prescrites et desdites valeurs mesurées, lesdites valeurs d'étalonnage incluant une valeur de pente et une valeur de décalage, et lesdits moyens de compensation (304, 306, 308, etc.) sont configurés pour multiplier ladite valeur mesurée par ladite valeur de pente pour définir un produit et additionner ladite valeur de décalage audit produit pour compenser la sensibilité ainsi que le décalage desdits signaux de sortie du capteur.

2. Circuit électronique (300) selon la revendication 1, où ledit dispositif de compensation (304,306,308 etc.) inclut des moyens pour compenser automatiquement des erreurs dans lesdits signaux de sortie résultant des différences de température.

3. Circuit électronique (300) selon la revendication 1 ou 2, où ledit capteur (13) est un capteur analogique.

4. Circuit électronique (300) selon la revendication 3, où ledit capteur (43) est un capteur linéaire.

5. Circuit électronique (300) selon la revendication 3 ou 4, où ledit capteur (43) est un capteur à effet Hall.

6. Circuit électronique (300) selon l'une des revendications précédentes, où lesdits moyens de compensation (304, 306, 308, etc.) sont intégrés audit capteur (43).

7. Circuit électronique (300) selon l'une des revendications précédentes, où lesdits signaux de sortie compensés sont des signaux analogiques.

8. Circuit électronique (300) selon l'une des revendications de 1 à 6, où lesdits signaux de sortie compensés sont des signaux numériques.

9. Circuit électronique (300) selon l'une des revendications précédentes, où lesdits moyens de stockage (306) comportent une mémoire non-volatile pour stocker lesdites valeurs d'étalonnage.

10. Circuit électronique (300) de la revendication 9, où ladite valeur non-volatile est une mémoire morte effaçable et programmable électriquement (EEPROM).

11. Circuit électronique (300) selon l'une des revendications précédentes, où ledit capteur (43) est un capteur angulaire.

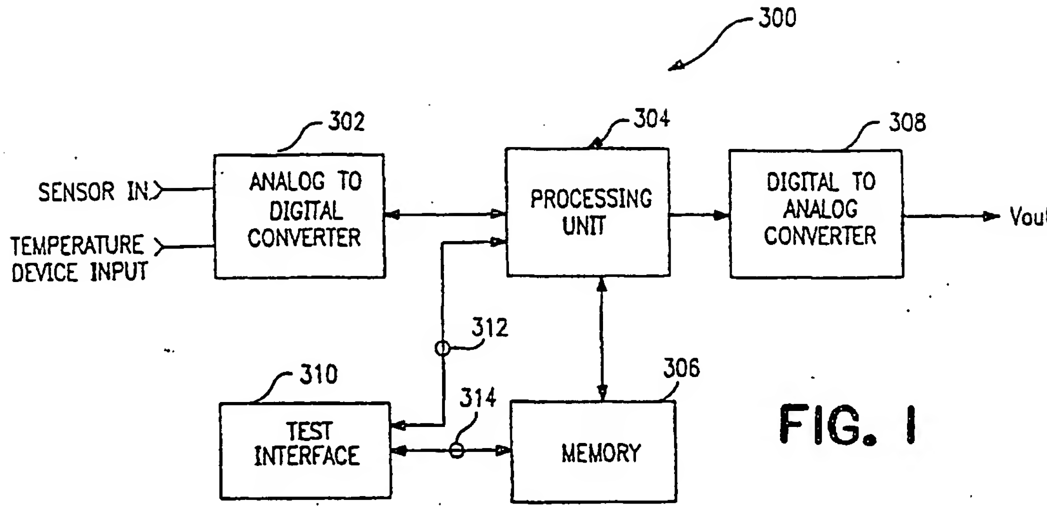

300
302
304
308
SENSOR IN
TEMPERATURE DEVICE INPUT
ANALOG TO DIGITAL CONVERTER
PROCESSING UNIT
DIGITAL TO ANALOG CONVERTER
Vout
312
310
306
314
TEST INTERFACE
MEMORY

FIG. 1

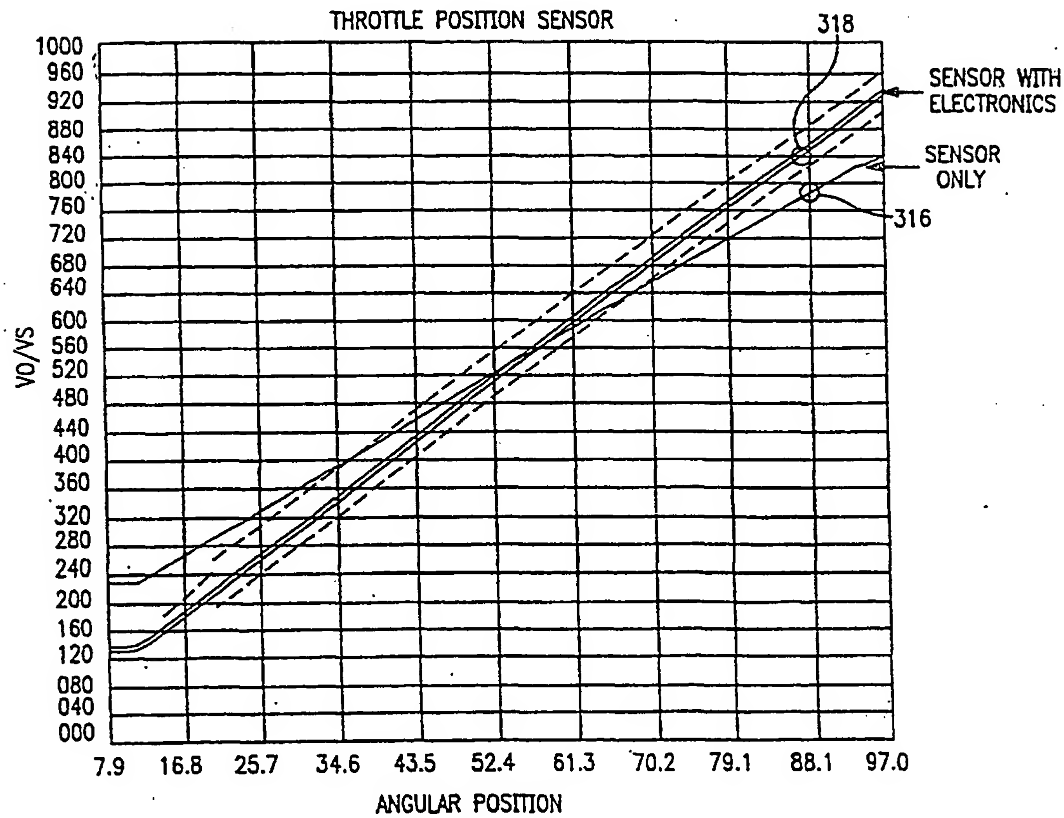
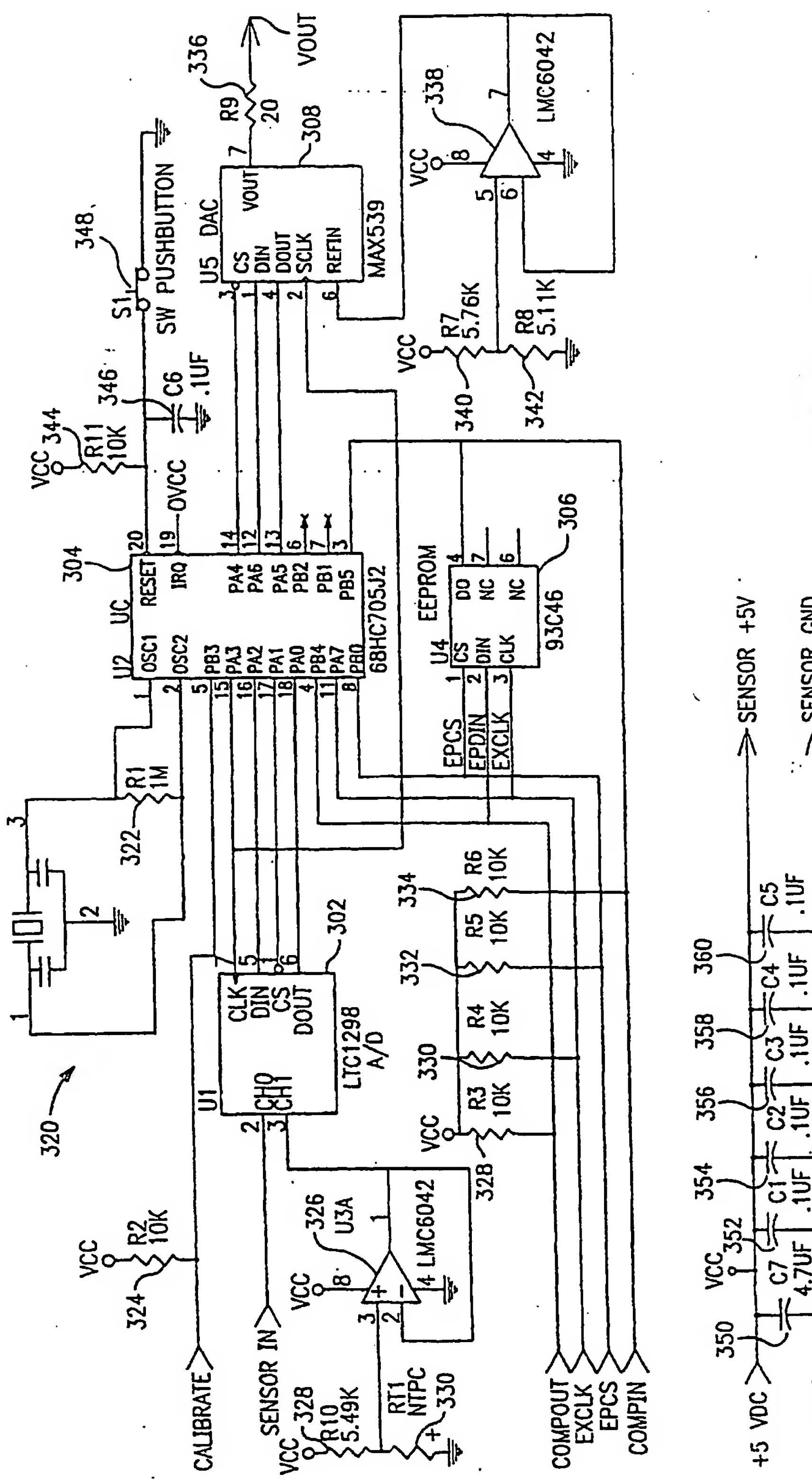

THROTTLE POSITION SENSOR
318
SENSOR WITH ELECTRONICS
SENSOR ONLY
316
VO/VS
1000
960
920
880
840
800
760
720
680
640
600
560
520
480
440
400
360
320
280
240
200
160
120
080
040
000
7.9
16.8
25.7
34.6
43.5
52.4
61.3
70.2
79.1
88.1
97.0
ANGULAR POSITION

FIG 2



320
U2 UC
68HC705J2
RESET
IRQ
OSC1
OSC2
304
VCC
R11 10K
344
346
C6 .1UF
S1
348
SW PUSHBUTTON
OVCC
U5 DAC
MAX539
CS
DIN
DOUT
SCLK
REFIN
VOUT
308
R9 20
336
VOUT
VCC
338
LMC6042
R7 5.76K
R8 5.11K
340
342
U4
EEPROM
93C46
306
EPCS
EPDIN
EXCLK
R1 1M
322
U1
LTC1298 A/D
CLK
DIN
CS
DOUT
CH0
CH1
302
VCC
R2 10K
324
CALIBRATE
SENSOR IN
326
U3A
LMC6042
VCC
R10 5.49K
328
RT1 NTPC
330
R3 10K
R4 10K
R5 10K
R6 10K
328
330
332
334
COMPOUT
EXCLK
EPCS
COMPIN
SENSOR +5V
SENSOR GND
+5 VDC
GND
350
352
354
356
358
360
C7 4.7UF
C1 .1UF
C2 .1UF
C3 .1UF
C4 .1UF
C5 .1UF

FIG. 3

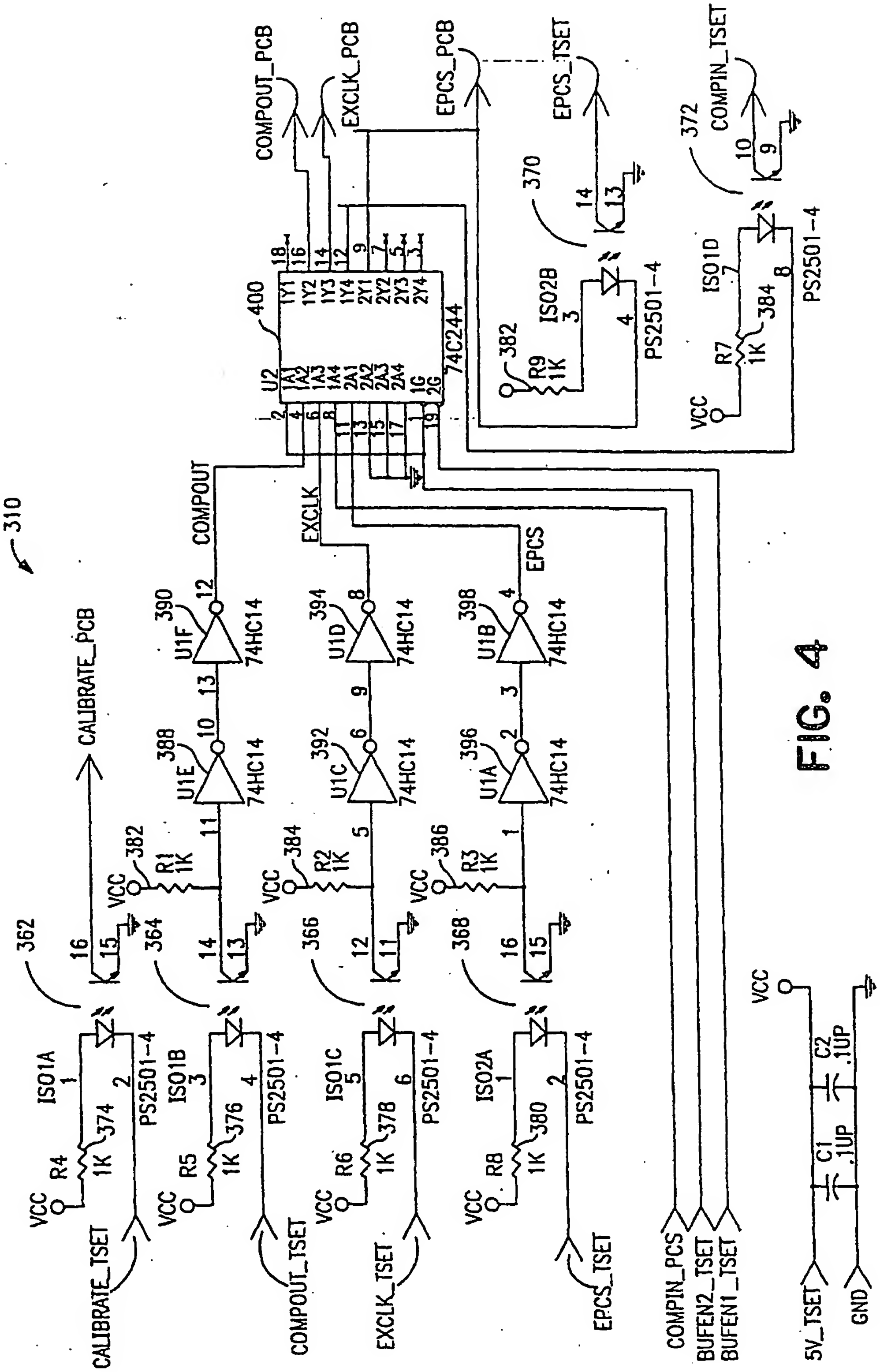

310
CALIBRATE_TSET
COMPOUT_TSET
EXCLK_TSET
EPCS_TSET
COMPIN_PCS
BUFEN2_TSET
BUFEN1_TSET
5V_TSET
GND
CALIBRATE_PCB
COMPOUT_PCB
EXCLK_PCB
EPCS_PCB
COMPIN_TSET
COMPOUT
EXCLK
EPCS
74HC14
74C244
PS2501-4
VCC

FIG. 4

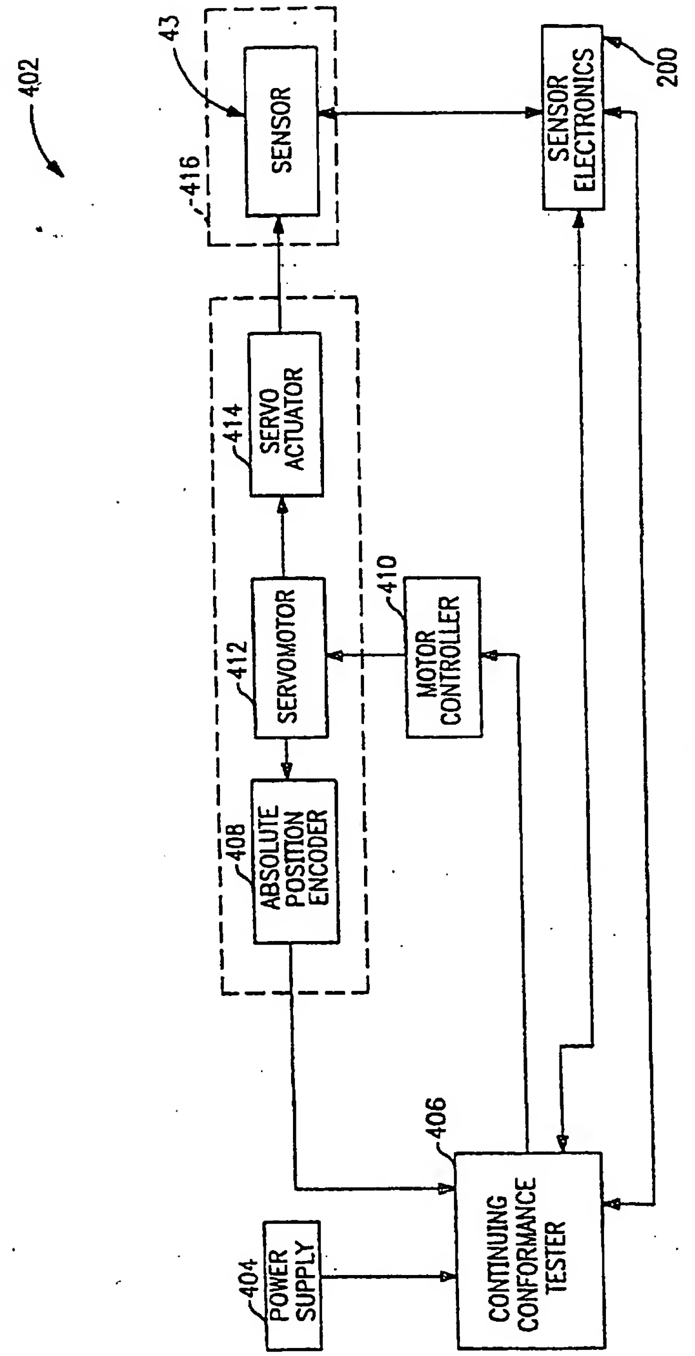

402
43
416
SENSOR
SENSOR ELECTRONICS
200
414
SERVO ACTUATOR
412
SERVOMOTOR
410
MOTOR CONTROLLER
408
ABSOLUTE POSITION ENCODER
406
CONTINUING CONFORMANCE TESTER
404
POWER SUPPLY

FIG. 5

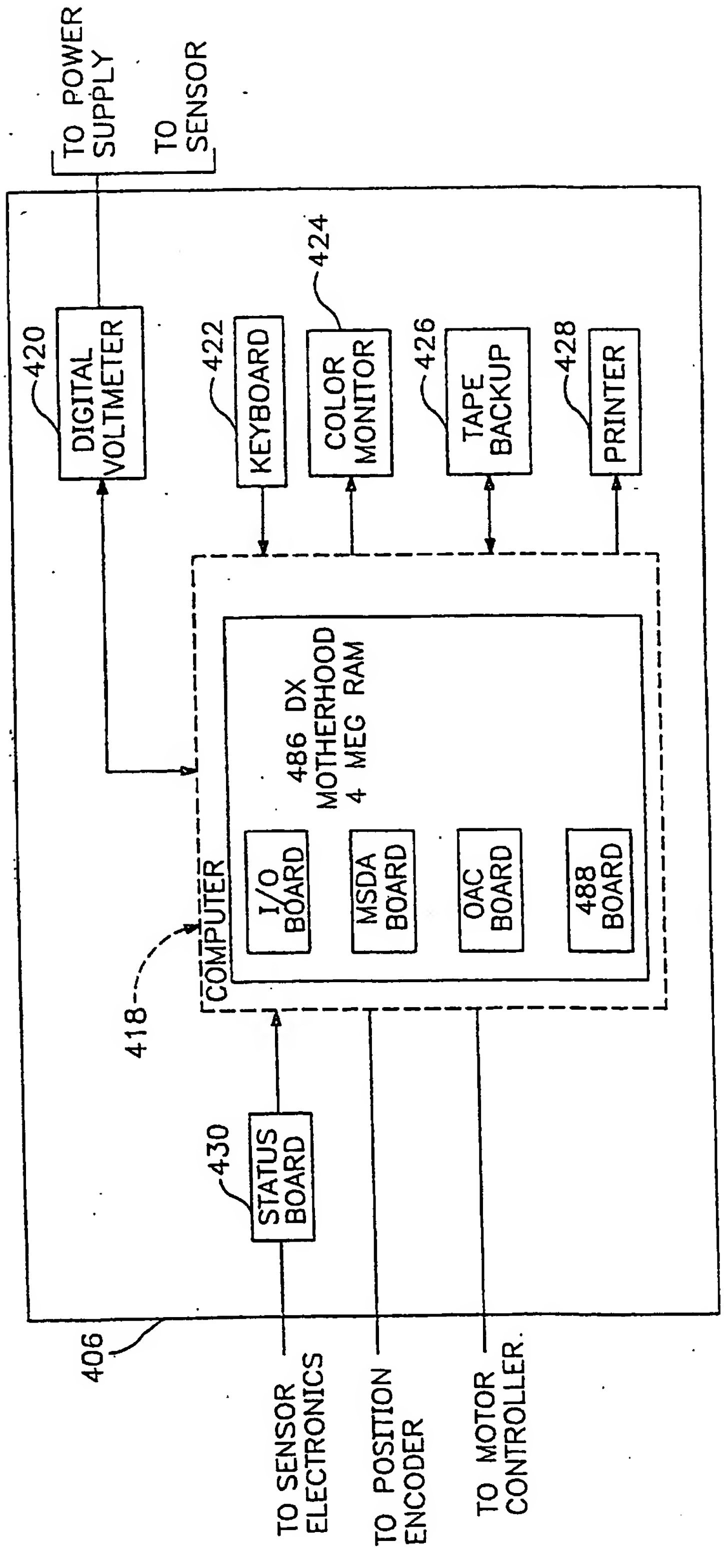

TO POWER SUPPLY
TO SENSOR
DIGITAL VOLTMETER
420
KEYBOARD
422
COLOR MONITOR
424
TAPE BACKUP
426
PRINTER
428
486 DX MOTHERHOOD 4 MEG RAM
I/O BOARD
MSDA BOARD
OAC BOARD
488 BOARD
COMPUTER
418
STATUS BOARD
430
406
TO SENSOR ELECTRONICS
TO POSITION ENCODER
TO MOTOR CONTROLLER

FIG. 6

	CALIBRATION ANGLE	MEASURED	IDEAL	M	B	
Q0	14.4	1.170	0.825			
Q1	17.4	1.262	0.965	1.522	−.955	
Q2	20.4	1.358	1.104	1.448	−.862	
Q3	34.8	1.856	1.774	1.345	−.722	
Q4	49.2	2.418	2.444	1.192	−.438	
Q5	63.6	3.030	3.113	1.053	−.199	
Q6	78.0	3.561	3.783	1.267	−.710	
Q7	92.4	4.037	4.452	1.405	−1.220	

FIG. 7

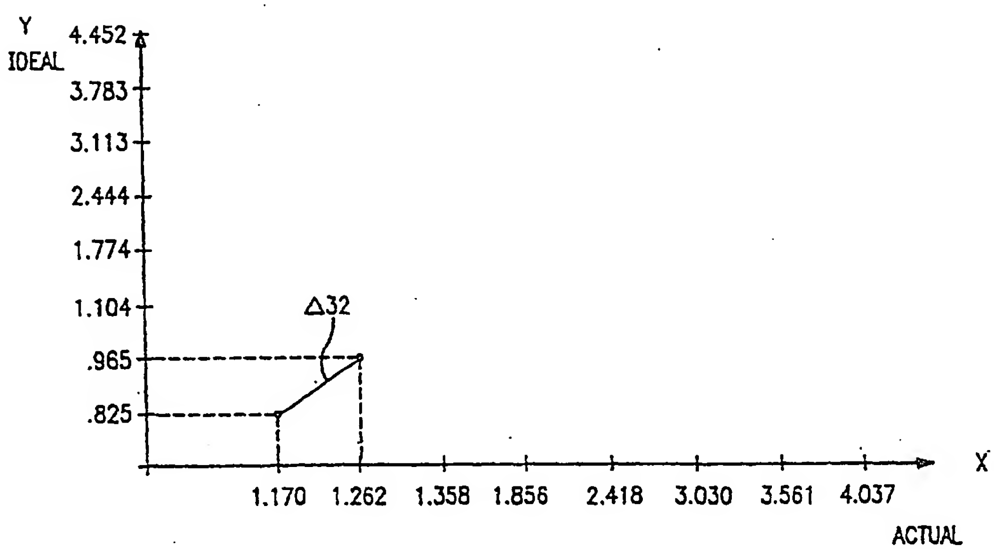


FIG. 8

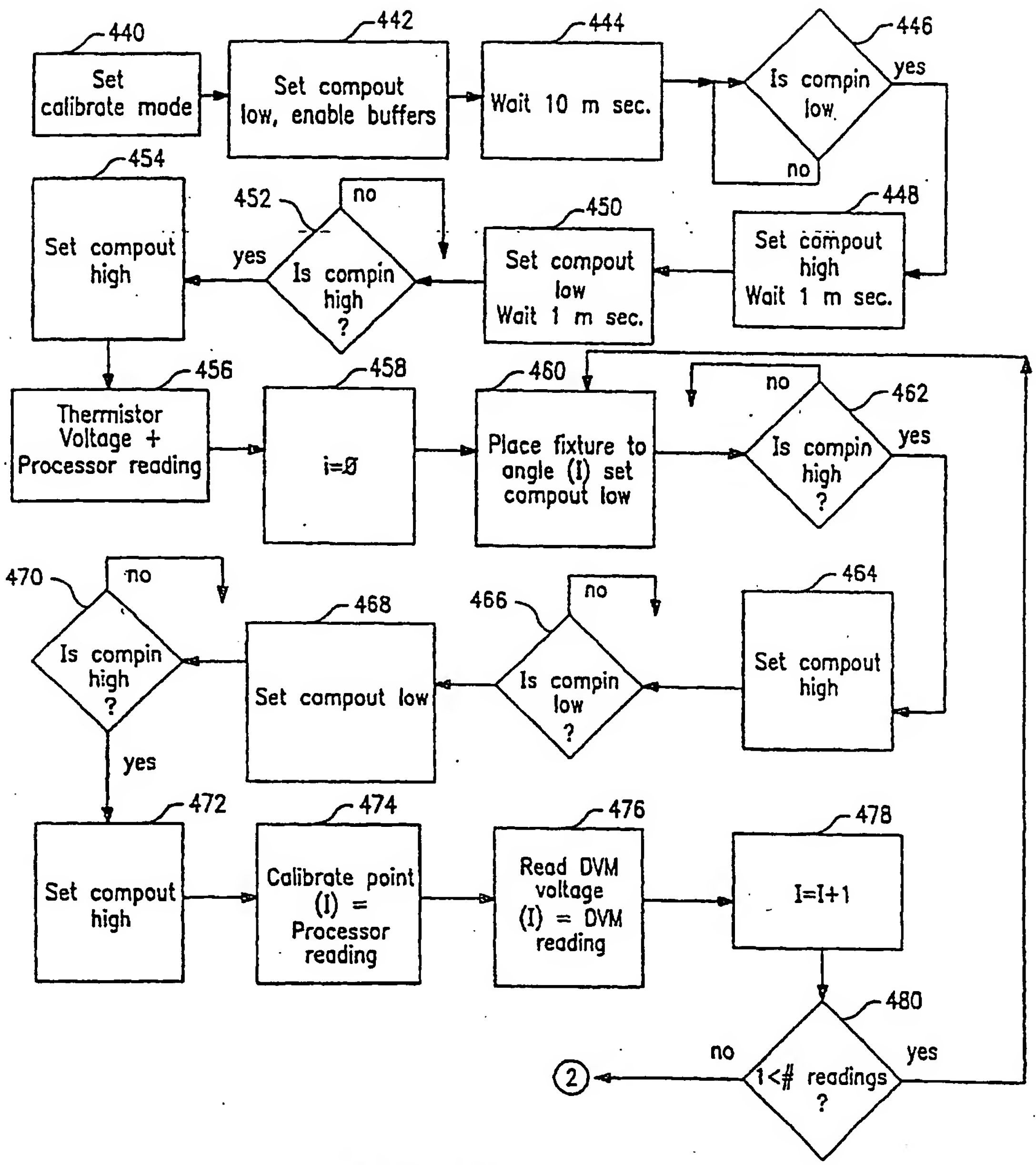

440
Set calibrate mode
442
Set compout low, enable buffers
444
Wait 10 m sec.
446
Is compin low
yes
no
448
Set compout high Wait 1 m sec.
450
Set compout low Wait 1 m sec.
452
Is compin high ?
no
yes
454
Set compout high
456
Thermistor Voltage + Processor reading
458
i=Ø
460
Place fixture to angle (I) set compout low
462
Is compin high ?
no
yes
464
Set compout high
466
Is compin low ?
no
468
Set compout low
470
Is compin high ?
no
yes
472
Set compout high
474
Calibrate point (I) = Processor reading
476
Read DVM voltage (I) = DVM reading
478
I=I+1
480
I<# readings ?
no
yes
2

FIG. 9

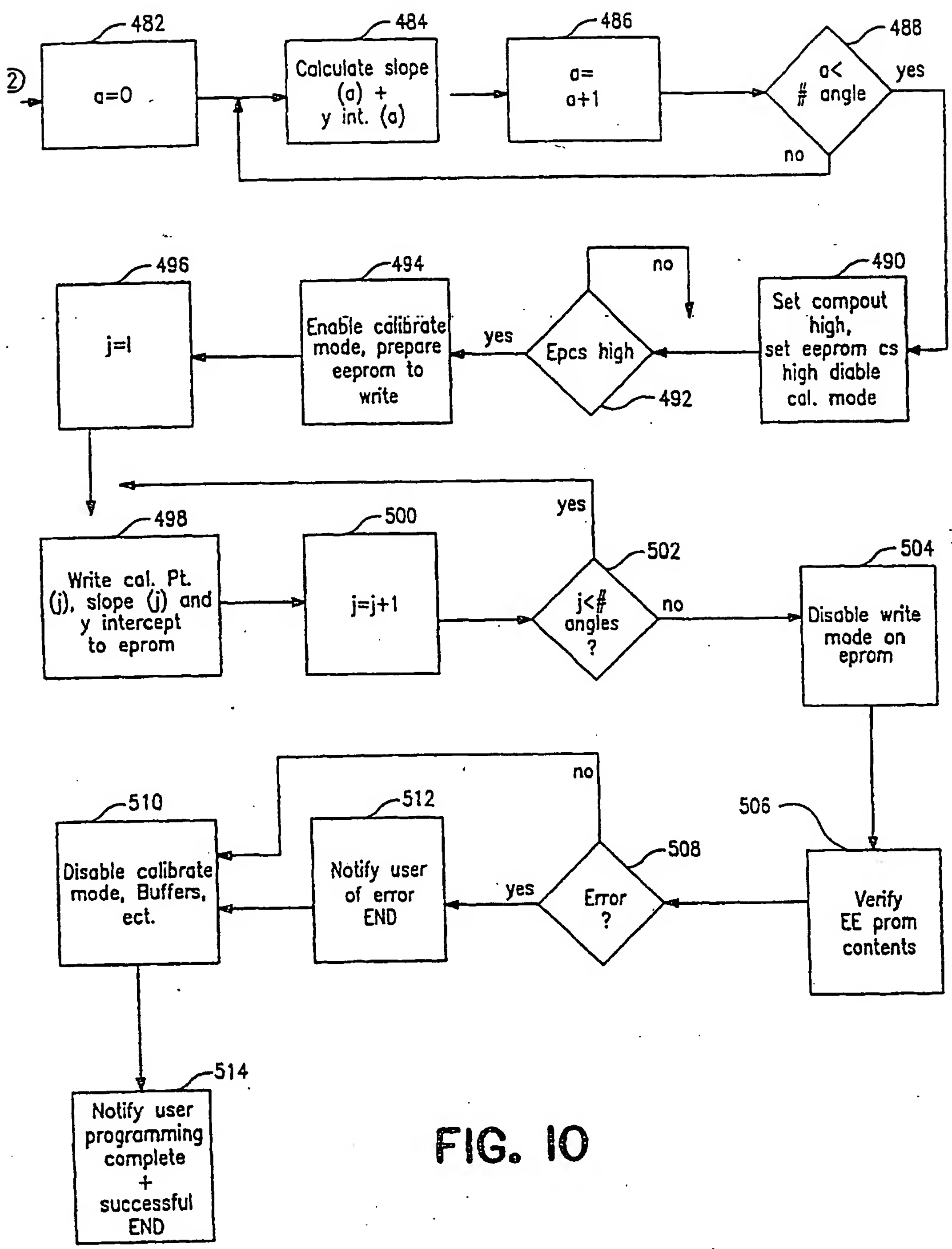

2
482
a=0
484
Calculate slope (a) + y int. (a)
486
a= a+1
488
a< # angle
yes
no
490
Set compout high, set eeprom cs high diable cal. mode
492
Epcs high
no
yes
494
Enable calibrate mode, prepare eeprom to write
496
j=I
498
Write cal. Pt. (j), slope (j) and y intercept to eprom
500
j=j+1
502
j<# angles ?
yes
no
504
Disable write mode on eprom
506
Verify EE prom contents
508
Error ?
yes
no
512
Notify user of error END
510
Disable calibrate mode, Buffers, ect.
514
Notify user programming complete + successful END

FIG. 10

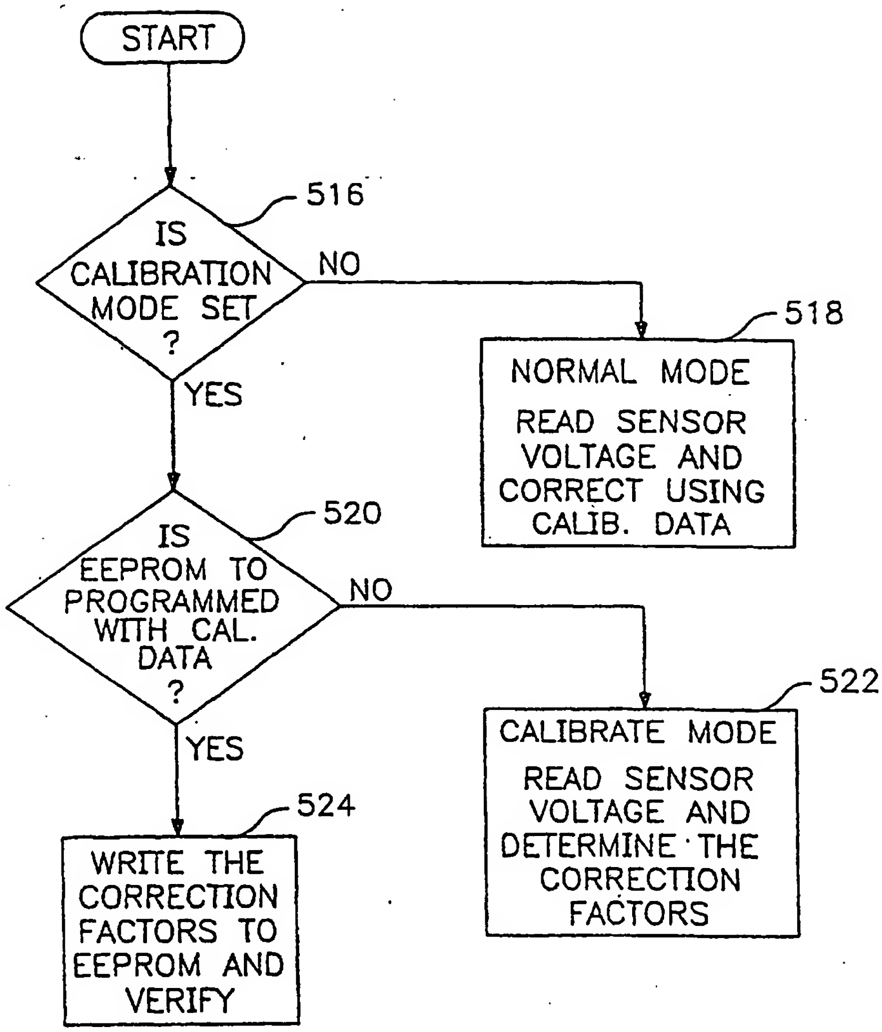

START
516
IS CALIBRATION MODE SET ?
NO
518
NORMAL MODE
READ SENSOR VOLTAGE AND CORRECT USING CALIB. DATA
YES
520
IS EEPROM TO PROGRAMMED WITH CAL. DATA ?
NO
522
CALIBRATE MODE
READ SENSOR VOLTAGE AND DETERMINE THE CORRECTION FACTORS
YES
524
WRITE THE CORRECTION FACTORS TO EEPROM AND VERIFY

FIG. 11

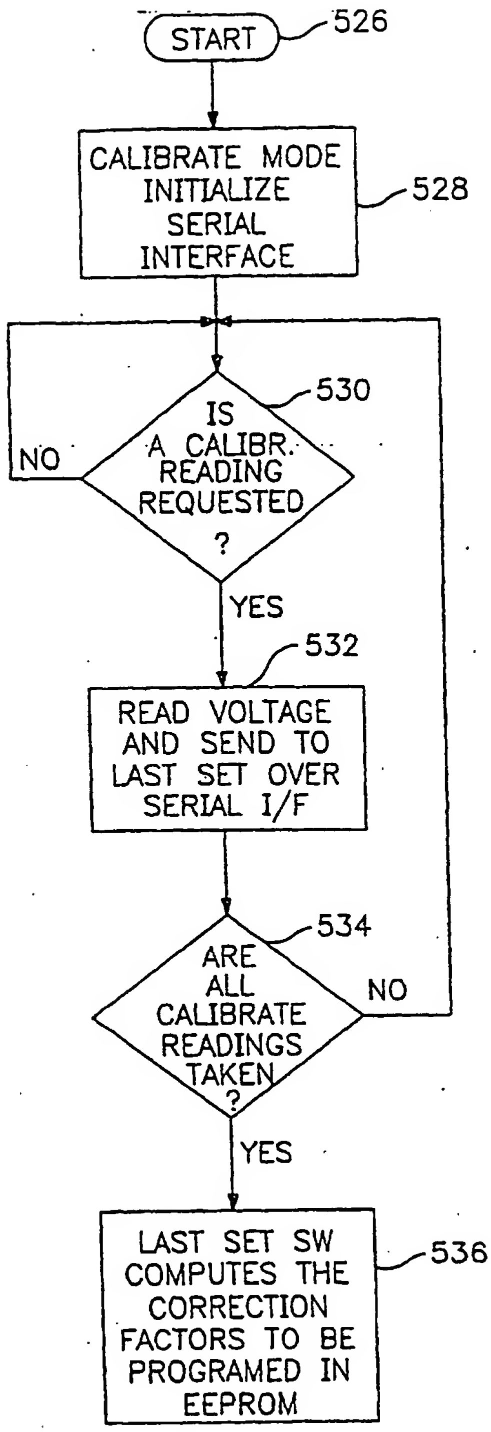

START
526
CALIBRATE MODE INITIALIZE SERIAL INTERFACE
528
IS A CALIBR. READING REQUESTED ?
530
NO
YES
532
READ VOLTAGE AND SEND TO LAST SET OVER SERIAL I/F
ARE ALL CALIBRATE READINGS TAKEN ?
534
NO
YES
LAST SET SW COMPUTES THE CORRECTION FACTORS TO BE PROGRAMED IN EEPROM
536

FIG. 12

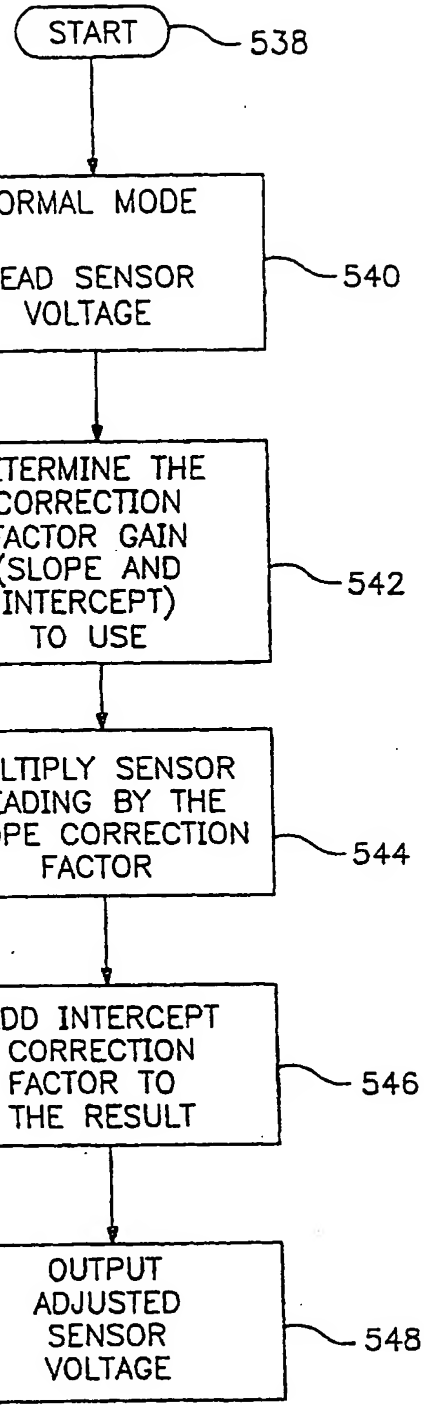

START
538
NORMAL MODE
READ SENSOR VOLTAGE
540
DETERMINE THE CORRECTION FACTOR GAIN (SLOPE AND INTERCEPT) TO USE
542
MULTIPLY SENSOR READING BY THE SLOPE CORRECTION FACTOR
544
ADD INTERCEPT CORRECTION FACTOR TO THE RESULT
546
OUTPUT ADJUSTED SENSOR VOLTAGE
548

FIG 13